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Efficiency analysis of fisheries using stock proxies

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ABSTRACT

This study proposes three methods for technical efficiency (TE) estimation using three fish stock proxy measures while applying the stochastic production frontier (SPF) approach. We apply these methods to two Vietnamese offshore fisheries, gillnet and hand-line, for which measures of stock abundance are unavailable. Based on the assumption of unitary elasticity for both effort and the stock index, our results show that using data envelopment analysis (DEA) is more robust than catch-per-unit-effort (CPUE) measures in deriving a composite stock index to account for differences in stock conditions between periods. The SPF model using the DEA estimate of the stock index is free of production-related assumptions and is not subject to a distortion in the measures of production elasticities. Based on the consistency conditions of the efficiency estimates, we find no difference between efficiency scores based on CPUE or DEA measures. When the average characteristics of the vessels over periods are similar, the CPUE measures are not subject to a distortion in the measures of TE and can provide robust efficiency estimates. We also find that the CPUE index can be a good empirical approximation for stock size changes in fisheries with limited information. The empirical results indicate a decrease in stock abundances - probably due to overfishing of offshore resources.

1. Introduction

The efficient utilization of resources associated with fishery production and the sustainable management of marine resources are considered crucial issues in maximizing the social benefits of marine fisheries (Sharma and Leung, 1999). An examination of technical efficiency (TE) can provide an understanding of the relationship between inputs and the resultant outputs.[1] This is defined as an essential pre-condition for economically effective fisheries management (Pascoe et al., 2003a).

As output from fishing is generally a function of the inputs employed (effort) and the fish resources available, estimating production functions ideally requires information on both effort and stock (Eide et al., 2003; Hannesson, 1983). However, information on stock abundance is often unavailable, particularly in developing countries. Thus, some proxy measures are required to take into account the effects of changes in stock conditions across periods on catches. In addition, the estimation of production frontiers in multi-species fisheries requires a composite stock index of all species caught. This index has to reflect the relative impact of changes in the abundance of each species on the overall composite measure of output. Failure to take into account these effects will lead to the effects of changes in stock size on catch being captured in the inefficiency component of the model (Andersen, 2005; Pascoe and Herrero, 2004). As a result, the estimates of efficiency can be biased. This study uses primary data on catch, revenue, cost and effort to estimate stock. Such data and bioeconomic modelling have also previously been used in fisheries analysis when stock assessments are lacking (Thuy and Flaaten, 2013).

The objective of this study is to analyse three TE estimation methods with different fish stock proxy measures employing the stochastic production frontier (SPF) approach. The methods are applied to two Vietnamese offshore open-access fisheries in the South China Sea (SCS) where regular stock surveys have not been

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[1] Among several approaches that can be found in the literature for measuring TE (Herrero, 2005), the SPF approach is widely used in many fisheries around the world (Fousekis and Klonaris, 2003; Grafton et al., 2000; Kirkley et al., 1995, 1998; Kompas et al., 2004; Pascoe and Coglan, 2002; Pascoe and Mardle, 2003; Sharma and Leung, 1999; Squires et al., 2003; Tingley et al., 2005). The stochastic nature of the fishing industry has led researchers to estimate efficiency using econometric approaches (Kirkley et al., 1998; Pascoe and Herrero, 2004).

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undertaken. The three methods of fish stock proxy measures investigated in this paper are as follows:

Method 1: An index of stock abundance is derived based on changes in the average level of CPUE over time and this index is directly incorporated in the production frontiers as an explanatory variable. Comitini and Huang (1967) used CPUE as a measure of stock abundance in a Cobb–Douglas production function in the North Pacific halibut fishery. Greenville et al. (2006) and Kirkley et al. (1995, 1998) used the CPUE indices of a reference fleet directly interposed into translog production frontiers. Eggert (2000) used the overall average landing value as a proxy of stock availability to analyse the Swedish trawling fishery for Norway lobster, and Pascoe and Coglan (2002) developed an index of the average value per hour fished in a sample of vessels as an index of stock biomass. Using this method, an implicit assumption is made about the unitary elasticity of fish stock and effort.

Method 2: Instead of using the CPUE index as an explanatory variable per se, it is used to adjust the output measure to allow the effects of stock change on output to be incorporated in the analysis (Pascoe and Herrero, 2004). The assumption tested is constant returns to effort.

Method 3: The dependent variable (catch) is adjusted using a composite stock effect index, which is referred to as the technical change component of the Malmquist index. The DEA analysis is used in configurations such that within-period variations in efficiency are independent of the underlying stock, and between-period differences in efficiency are thereby assumed to be directly proportional to changes in stock abundance. This method was developed by Pascoe and Herrero (2004) and was applied to two Spanish fisheries operating in the South Atlantic – one single-species fishery and one multi-species fishery. This method was also applied in the studies of Herrero (2005), Herrero and Pascoe (2003) and Tingley et al. (2005).

The remainder of this paper is organized as follows. Section 2 describes the study fisheries. Section 3 presents the theoretical basis of the three methods of fish stock proxies. Section 4 presents the model specifications in 4.1, followed by the data description in 4.2. The empirical results are presented in Section 5. Finally, the key features of the results are discussed in Section 6 and the concluding remarks are highlighted in Section 7.

2. The study fisheries

The methods are applied to Vietnamese offshore gillnet and hand-line fisheries operating in the SCS. These two fisheries are located in Khanh Hoa province – a coastal province in Southern Central Vietnam. The offshore fishing area has been open access since its inception and a minor resource tax was abolished. In addition, it has been subsidized by government aid schemes since 1997. At present, a subsidy programme is running (as of 2010) to provide three main types of support: fuel cost support, insurance subsidies and loans at below-market interest rates (Duy and Flaaten, 2016; Duy et al., 2015). The fuel cost subsidies are based on the engine size of vessels. Insurance subsidies cover 50% of vessel insurance costs and 100% of accident insurance costs for fishers. Some vessels have been supported with loans at below-market interest rates. According to the Department of Capture Fisheries and Resources Protection (DECAFIREP, 2012) Khanh Hoa's offshore fleet was about 1041 units in 2012, of which gillnet and hand-lines were the major types of fishing gear. Gillnet and hand-line vessels account for 25% (258 units) and 15% (153 units) of the fleet, with a total capacity of 78,211 horsepower (HP) (on average 303HP/unit) and 42,942HP (283HP/unit), respectively.

The gillnet fishery has relatively more vessels than the hand-line fishery. However, these two fisheries have the same operating characteristics. They are both multi-species fisheries. The fishing season is year-round, lasting from October to September of the following year, and is divided into two fishing seasons – the northeast monsoon (from October to March) and the southwest monsoon (from April to September). The offshore vessels often stay onshore for repairs and maintenance from either August to September or September to October. The fishing grounds for these vessels are the offshore waters of the central sea region (bounded by latitudes 11°30′N and 14°00′N and by longitudes 109°30′E and 114°00′E) and the open sea zone of the south-eastern area (bounded by latitudes 6°00′N and 11°30′N and by longitudes 105°00′E and 114°00′N). The target fish species of the gillnetters and hand-liners are migratory pelagic species (e.g., tuna species). Hence, the actual fishing grounds depend on the direction of movement and the aggregation of these species. In the northeast monsoon, tuna species are often found in the offshore sea areas of the central provinces from Phu Yen to Vung Tau and the central SCS (10°30′N-14°00′N, 110°00′E-114°00′E). The offshore vessels move to the south-eastern waters and southwest of the Spratly Archipelago (6°00′N-10°30′N, 105°00′E-114°00′E) in the southwest monsoon. Tuna species are also fished in this second season in the territorial waters of the provinces from Phu Yen to Binh Thuan, located at a distance of around 50–100 nautical miles from the shore.

The main target species in the gillnet fishery include striped tuna (*Sarda orientalis*, Scombridae), skipjack tuna (*Katsuwonus pelamis*, Scombridae) and mackerel species (e.g., Indo-Pacific king mackerel (*Scomberomorus guttatus*, Scombridae), wahoo (*Acanthocybium solandri*, Scombridae), narrow-barred Spanish mackerel (*Scomberomorus commerson*)), as well as some other species caught as incidental bycatch. For the hand-line fishery, yellowfin tuna (*Thunnus albacares*, Scombridae) and bigeye tuna (*Thunnus obesus*, Scombridae) are the main target species, while a small number of other species comprise bycatch. The fishing activities of the hand-line vessels are conducted with light. Lamps are located along both sides of the vessel to attract squid, which are in turn used as bait. The hand-line gear uses a single hooked line attached to a bamboo pole to catch the fish.

3. Methodology

The Schaefer harvest function (Schaefer, 1957) is commonly used in bioeconomic studies, given as $H_t = H(E_t, S_t) = qE_tS_t$, assuming a bi-linear relationship between the two inputs, fishing effort (E_t) and stock biomass (S_t), and the produced catch (H_t) in a single period t. Furthermore, q is the catchability coefficient, constant or variable over time, which may include technological progress of effort (Eide et al., 2003).[2] The Schaefer harvest function implies that the effort–output elasticity and the stock–output elasticity are both equal to one. Catch per unit effort ($CPUE_t = H_t/E_t$) is thus defined to be proportional to the stock size. In other words, an increase in stock biomass leads to an increase in the catch at the same rate, given a fixed fishing effort. As a result, an average CPUE index of observed vessels has been used as a proxy for stock abundance in previous studies of production functions and frontiers in fisheries (Comitini and Huang, 1967; Greenville et al., 2006; Kirkley et al., 1995, 1998). However, the assumption of constant returns to both effort and stock needs to be validated.

The more general Cobb–Douglas production function that has been used in some empirical studies involves two additional parameters given by $H_t = H(E_t, S_t) = qE_t^{\beta_E}S_t^{\beta_S}$, where the two additional parameters are the effort–output elasticity β_E and the stock–output elasticity β_S (Eide et al., 2003; Hannesson, 1983).

[2] For SPF, inefficiency terms could be added to the harvest function. However, this term is dropped for simplicity of concept explanations.